KOCH SLOT LOOP ANTENNA FOR OFF-BODY COMMUNICATIONS

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Abstract: In this contribution, we describe the design of a Koch slot loop antenna with a tuning stub fed by a coplanar waveguide (CPW) for a wireless body-centric communication. The antenna is designed to operate in the ISM frequency band from 5.725 GHz to 5.875 GHz. The study shows properties of the antenna from the viewpoint of impedance matching and radiation patterns. The impedance matching at the resonant frequency can be acquired by a tuning stub. The designed CPW-fed slot antenna exhibits low radiation losses.

Keywords: Fractal antenna, Koch antenna, body centric communication, human body model.

1. INTRODUCTION

At present, wireless body area networks (WBAN) attract attention thanks to promising applications in the field of biomedical engineering, healthcare, assisted living, etc. In case of antennas for off-body communication, it is required that an antenna should have maximum radiation in a normal direction to the antenna plane, it should be a low profile, a low weight, and have a compact size [1, 2].

The antenna structure is optimized to operate in vicinity of a human body in the ISM frequency band (5.725 GHz to 5.875 GHz). We used a simplified three-layer tissue model and a voxel Duke model for simulations and optimization of the antenna located close to a body [3]. The designed antenna is simulated and optimized in CST Microwave Studio.

2. ANTENNA CONCEPT

In order to keep physical dimensions of the antenna constant when prolonging the magnetic current length of the loop, the fractal Koch geometry can be applied for shaping the loop. We follow the procedure of the iterative synthesis of the Koch fractal described in [4]. This procedure does not increase the dimension of the antenna, but the physical length of the wire is prolonged by a factor $(4/3)^n$, where n is the number of the iteration (see Fig. 1).

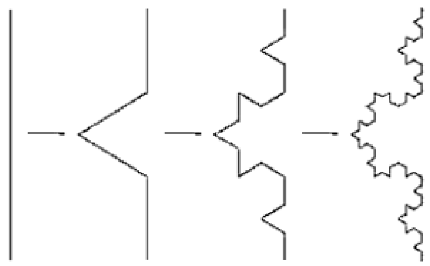

Fig. 1. Koch figures: From the left side is number of the iteration: zeroth, first, second, third.

The designed slot loop antenna is of a shape of a Koch snowflake created from the second iteration of the Koch figure. The width of the slot is 0.40 mm. The length of each element is given by $l_e = 0.5 \times m \times l1 \times (4/3)^n$, where *m* denotes the number of elements of the Koch snowflake, *l1* indicates the length of a straight wire and *n* is the number of the iteration. The length of the element is chosen to be equal to the wavelength on the substrate.

In the top point, the slot of the Koch snowflake is interrupted by a narrow strip of the width *w2*. A serial susceptance in the circuit a magnetic current, which is reached by using mentioned interruption, is used for tuning the input impedance of the antenna in resonance.

The loop antenna is fed by a CPW with the characteristic impedance of 50 Ω. We follow the procedure of the design of CPW feeder in [5]. The width of the signal strip and the gap between the signal strips is summarized in TABLE I. The dimension of the tuning stub in CPW feeding line is given by TABLE I. this dimensions provide a regular impedance matching of the slot antenna.

The antenna was designed for the substrate Arlon 25N with the dielectric constant $\varepsilon_r = 3.38$, the loss tangent tan $\delta = 0.0025$, and the height h = 0.762 mm. The prototype of the antenna was completed by a SMA connector [7].

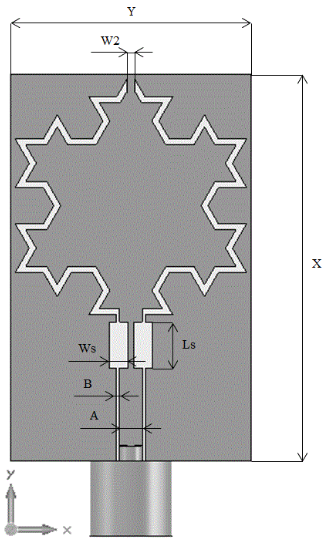

Fig. 2. Koch slot antenna.

TABLE I. ANTENNA OPTIMAL DIMENSIONS

Description	X	Y	W2	Ws
Length [mm]	*25.30*	*16.00*	*0.50*	*1.26*
Description	**Ls**	**B**	**A**	
Length [mm]	*3.4*	*0.20*	*1.50*	

3. HUMAN BODY MODEL

The designed antenna was simulated in proximity of a human body model to examine the influence of the body to antenna parameters. The simulations were carried out using a simple layered model (see Fig. 3) and a voxel phantom Duke model (see Fig. 4) of the body.

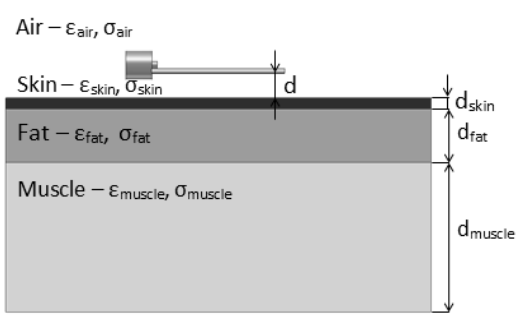

Fig. 3. Simple layered model.

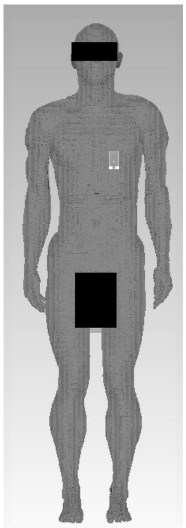

Fig. 4. Duke model.

The simple layered model was composed of three layers – skin, fat, muscle. From the viewpoint of propagation of electromagnetic waves, all the described layers are lossy dielectrics of specific thicknesses and complex permittivity.

- Skin is a planar organ, which plays the role of an external surface of an organism and protects it against surrounding environment. The thickness of the skin is between 0.4 mm and 4.0 mm.
- Fat is a reservoir of energy and a heat insulator. The thickness of the layer of fat is impossible to determine, because everyone has a unique anatomy.
- Muscles are tissues with elastic properties. Muscles are able to contract and relax. The layer of muscle has various thicknesses, which depends on the type of muscle and the location on the body.

The simple layered model is formed into a block of the basis 80 mm × 80 mm. The height of the model is given by thicknesses of layers representing the skin, the fat and the muscle. The relative permittivity and the height of each layer are summarized in TABLE II. The distance *d* between the human body model and the antenna was set to d = 5.00 mm [8].

TABLE II. THE MATERIAL PARAMETERS OF LAYERS OF HUMAN BODY MODELS AT THE FREQUENCY 5.8 GHZ.

	ε_r	σ (S/m)	tan δ	Thickness (mm)
Dry skin	*35.114*	*3.717*	*0.328*	*2.00*
Wet skin	*38.624*	*4.342*	*0.328*	*2.00*
Fat	*4.954*	*0.293*	*0.1383*	*10.00*
Muscle	*48.751*	*4.961*	*0.317*	*28.00*

In order to verify simulation results by measurements, we prepared an agar phantom. The phantom was a block of the basis 200 mm × 200 mm and the height 20 mm. The relative permittivity of the modified agar gelatin was ε_r = 45. In this time, it is impossible to create this phantom with more than one layer, but we are working on it.

Moreover, we have simulated the designed antenna close to voxel Duke model. The antenna was positioned near the right chest. That way, we can compare simulations of the slot loop in vicinity of a simple layered model and in the vicinity of the Duke model with measurements of the antenna in proximity of the agar phantom [7].

4. SIMULATION AND EXPERIMENTAL VERIFICATION

The Koch slot antenna was manufactured and the prototype was placed to the distance d = 5.00 mm from the agar phantom. In this configuration, we measured the frequency response of the reflection coefficient at the antenna input, and radiation patterns in the xz plane and the yz plane.

The frequency response of the reflection coefficient of the simulated and measured antenna is depicted in Fig. 5. In the frequency range from 5.725 GHz to 5.875 GHz, the reflection coefficient is lower than –15 dB. At the resonant frequency 5.8 GHz, the reflection coefficient at the antenna input is lower than –20 dB. The results show a good agreement of measurements and simulations using different human body models.

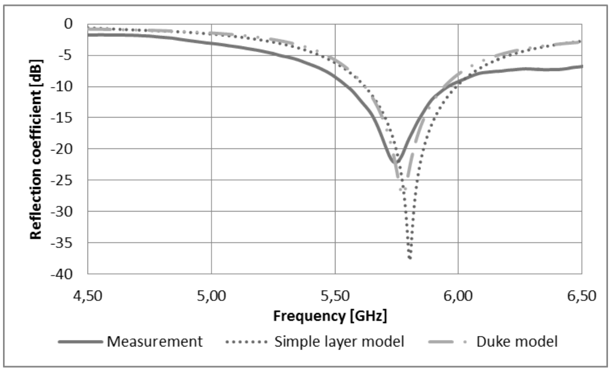

Fig. 5. Frequency response of the reflection coefficient at the antenna input.

The comparison of measured radiation patterns (the agar phantom) and simulated ones (the simple layered model) of the antenna are shown in Fig. 6 Radiation patters are normalized. The differences in radiation patterns are affected by lossy dielectric objects (phantoms), which absorb and reflect the radiated electromagnetic field. The interactions depend on the relative permittivity, thickness of all materials, and on the distance between the antenna and the phantom.

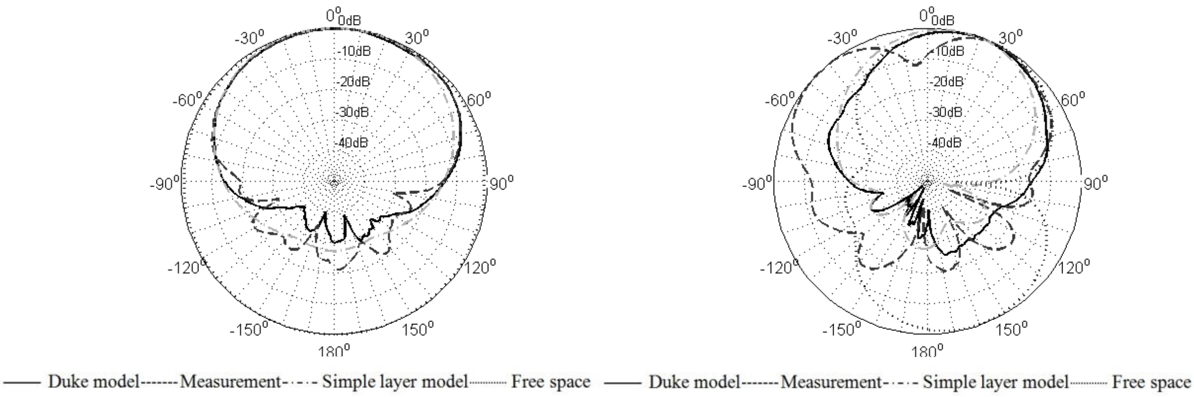

Fig. 6. On the left side: Radiation pattern of the antenna in xz plane at f = 5.8 GHz; On the right side: Radiation pattern of the antenna in yz plane at f = 5.8 GHz.

The gain and the efficiency of the antenna are summarized in TABLE III. TABLE II. Differences in values are caused by diverse forms of the models and their complexity such as the non-flat surface of the duke model and small dissimilarities in material properties [7].

TABLE III. THE SIMULATED GAIN AND THE EFFICICENCY OF THE PROPOSED ANTENNA

Description	Gain [dB]	Efficiency [%]
Free space	*3.85*	*97.86*
Simple layer model	*7.11*	*60.54*
Duke model	*5.97*	*49.93*

5. CONCLUSION

In this paper, we described the Koch slot loop antenna to be used for off-body communication. The antenna exhibits good radiation and impedance bandwidth in the 5.8 GHz ISM band. Measured and simulated results exhibited acceptable agreement. Hence, the Koch slot loop antenna can be a good candidate for off-body communications.

ACKNOWLEDGEMENT

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